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ON MINIMISING NOISE PROBLEMS CAUSED BY PASSENGER LIFTS IN STUDIO CENTRES

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Summary

A number of passenger lifts have been investigated as sources of noise and vibration. Typical measured results are presented, and a number of problems and solutions are discussed. Finally, some general recommendations are listed, indicating how noise nuisance may be avoided or remedied.

Index terms: *Acoustics; noise reduction*

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1. INTRODUCTION

So that physically handicapped persons should not be placed at an avoidable disadvantage, it has been BBC policy for some time to install passenger lifts in all studio centres. Some problems have been caused by lift noise in sensitive areas such as studios and control rooms, especially in small buildings such as Local Radio centres. This Report describes a programme of studies carried out over a period of about three years, during which time a number of measurements were made on a variety of lifts, both inside and outside the BBC.

Initially, it was considered possible that lifts of a particular design or from a particular manufacturer might be especially quiet, and that by recommending these products, potential problems could be minimised. To establish this, a large amount of data would be required. In any case, it appears that basic 'active' lift components are mostly manufactured by a small number of companies, then selected by lift manufacturers according to the requirements of a specific design. It is therefore unlikely that the use of a particular manufacturer would guarantee exceptionally quiet lifts.

In the many installations examined and measured, it was found that the major source of noise was different in almost every case. These findings indicate that the designer of a new installation should take precautions to ensure that all of the active components are prevented from transmitting excessive noise to the surrounding areas. Although this would add to the installation cost, it would usually be cheaper than having to take subsequent curative measures, with the likely disruption of normal work in surrounding areas.

In fact, the most obvious initial precaution appears to be the one least often taken. When installing a lift, especially in a new building, the potential noise nuisance can always be minimised by siting it *as far away as possible* from sensitive areas such as studios.

2. LIFTS AS SOURCES OF NOISE AND VIBRATION

2.1 Lift types

There are two types of lift mechanism: mechanical and hydraulic. The mechanical type consists of a winding engine at the top or bottom of the lift shaft; the lift car is suspended by wire ropes running over pulleys at the top of the shaft. The hydraulic type, which is more recent in origin, uses a pump to elevate a long hydraulic ram. The most common arrangement is for the ram to be placed in the lift shaft alongside the car, and to elevate the car by means of a pulley and wire rope or chain; the extension of the ram is thus half of the distance travelled by the car. The hydraulic system allows the pump to be sited at any level and within any reasonable distance of the lift shaft. Because of this flexibility, hydraulic lifts are almost always favoured in modern installations where space is often at a premium.

This Report presents only measurements made on hydraulic lifts.

2.2 Lift components: potential noise problems

2.2.1 Lift cars and doors

In their movement up and down the shaft, lift cars are laterally restrained by guide rails. The doors on each floor are usually electrically operated. Car guide rails and doors are both capable of generating noise and vibration, especially if not properly lubricated and adjusted. The potential problem is the same whether the lift is hoisted mechanically or hydraulically; however, in none of the installations examined were the lift car or doors the primary noise source.

2.2.2 Hydraulic rams

There are two ways in which hydraulic rams can generate excessive noise. The first is by friction in the rubber seals; the second is by ascending in a series of small 'jerks' because the hydraulic pump delivers fluid at an uneven rate. These two effects can cause noise and vibration both in the building and in the lift car itself.

2.2.3 Hydraulic pumps

There are three ways in which lift pumps can cause a noise nuisance. The first and most common is by generating vibration which is transmitted to the building; the second is by generating airborne noise; the third is by delivering fluid at a fluctuating rate (causing ram noise as mentioned above).

3. MEASUREMENTS ON THREE INSTALLED HYDRAULIC LIFTS

With the assistance of three lift manfacturers, three different installations were examined and measured. These were all small hydraulic systems; two were installed in residential buildings, the third in a multi-storey office block. For reasons of commercial confidentiality, the identity of the manufacturers will not be revealed. However, the results, as far as they are strictly comparable, suggest that there is little in the way of clear choice between the installations. A large number of measurements were made, and a representative selection of the results are presented here.

The environments in which the three lifts operated varied considerably, and this has been taken into account in the interpretation of results. For example, all pumps were mounted on thin rubber mats of an estimated 3 mm static deflection. Pump 1 sat on a concrete plinth of similar weight to the pump; this was supported by the concrete site slab via cork mountings of estimated static deflection 1 mm. Pump 2 sat on a concrete site slab, and Pump 3 on a lightweight metal ceiling framework.

3.1 Lift noise nuisance: dependence on conditions

3.1.1 Dependence on payload

Examination of the three hydraulic lift systems suggests that the noise and vibration generated is not closely dependent on the number of lift passengers. Subsequent measurements on a wider variety of hydraulic systems have confirmed this finding: payload will not therefore be considered further as a significant parameter. In fact, most of the lift measurements made in later work were with one passenger, who could conveniently operate the lift as required.

As an example, Fig. 1 shows the pump vibration of Lift 1 (as measured with an accelerometer on the pump casing) for different payloads; the effect of payload is scarcely greater than the variations between measurements made under nominally identical conditions.

3.1.2 Dependence on lift car direction

On ascent, the lift pump must operate to drive the hydraulic ram. On descent, however, the hydraulic fluid flows from the ram to the reservoir via a restrictor valve to limit the car speed. When the pump is operating, a range of vibration frequencies are generated: typically, these include electrical mains contributions (50 Hz and harmonics), motor contributions (chiefly at just under 25 Hz for a standard four-pole induction motor running with slip), and pump contributions (harmonics of motor speed which depend on pump type). When the restrictor valve is in use, the vibration generated seems to be broadband and without pronounced harmonics, as might be expected for turbulent fluid flow. The three pumps all generated higher vibration levels than the restrictor valves, so that ascent was always noisier than descent; the 10 to 20 dB difference shown in Fig. 1 for Lift 1 is typical.

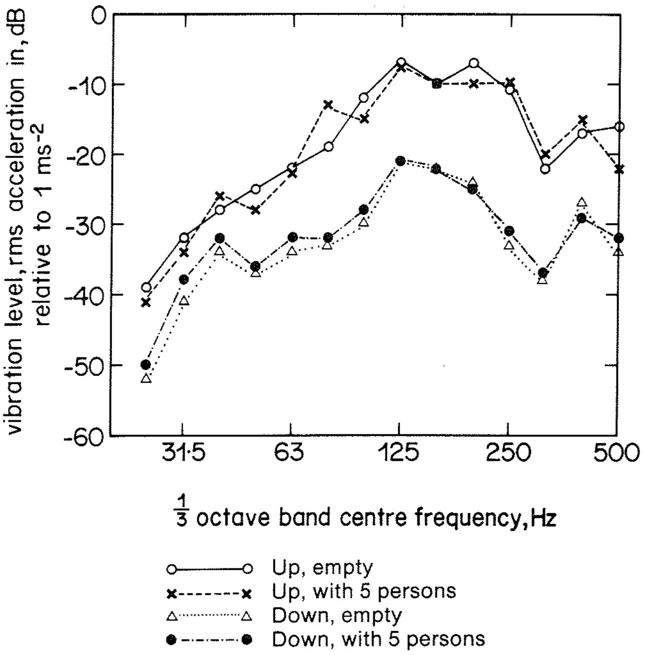

Fig. 1 - Lift 1: vibration of pump for various conditions.

As would be expected, pump room airborne noise seems to be closely related to pump vibration, and is affected in a similar way by changing the direction of travel. Hydraulic ram vibration and lift shaft noise are less dependent on the direction of travel, but invariably appear to be greater on ascent than descent.

Consequently, as an ascending lift seems to cause the maximum nuisance, all results quoted hereafter will pertain to this condition.

3.1.3 Dependence on other factors

The structure and layout of a building can have a considerable effect both on the measurement and the effect of lift noise and vibration. For example, a lift pump solidly bolted to a concrete site slab (rare in modern installations) will vibrate less than one set on antivibration mounts, but may transmit vibration more widely throughout the building. Conversely, a pump mounted in the attic space of a lightweight metal-framed building may vibrate more and cause more local noise, but may induce very little noise and vibration on the lower floors of the building.

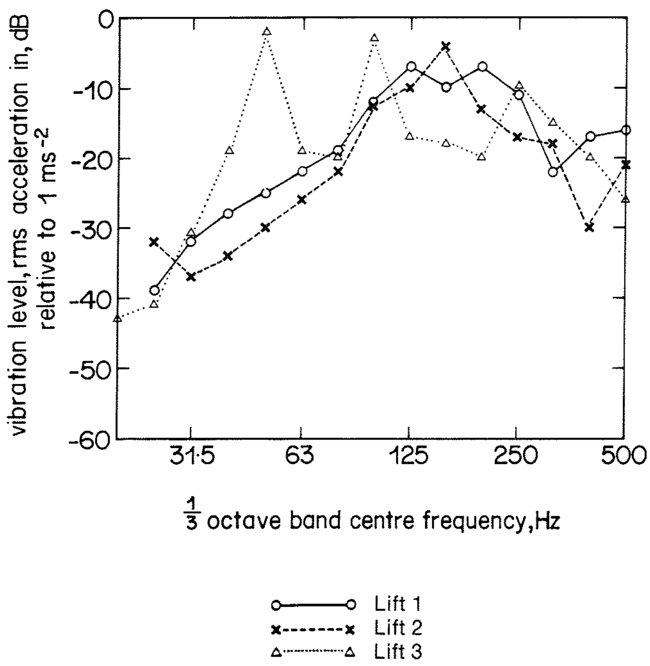

Fig. 2 - Comparison of pump vibration for three lifts: all travelling up, empty.

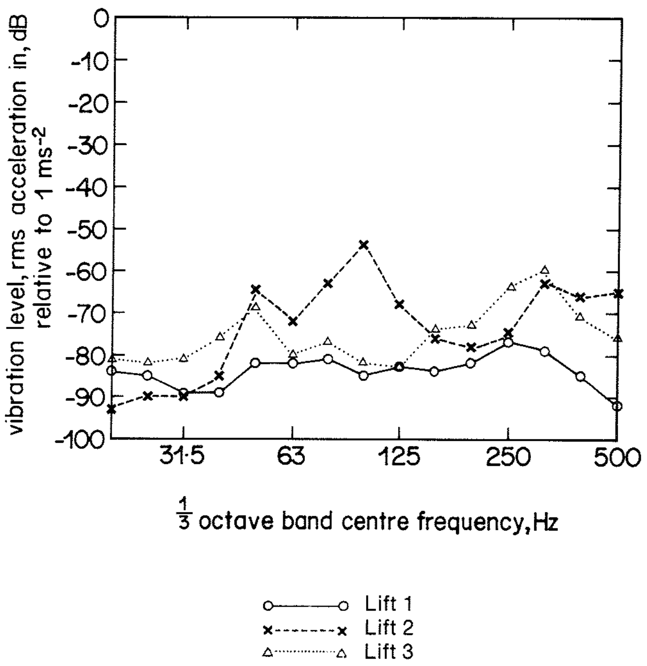

Fig. 3 - Vibration of concrete slab under ram for three lifts: all travelling up, empty.

To allow a useful estimation of the potential noise nuisance for a particular lift system, it is essential to take account of the surroundings in which a test system is evaluated, as well as those in which the final system will be installed.

3.2 Comparison of lifts

In this section, the three hydraulic lifts are compared in their different environments.

3.2.1 Pump vibration

Fig. 2 shows the pump vibration for the three lifts. Results are broadly similar over the frequency range 100 - 500 Hz; the large peaks exhibited by Lift 3 below 100 Hz may well occur because the pump is mounted in the attic of a new building with a very light metal frame.

3.2.2 Vibration of shaft floor under ram

All three lift shafts had a concrete floor which formed part of the building site slab. The vibration of the floor at the foot of the ram is shown in Fig. 3 for the three installations. From the plots it would appear that the ram of Lift 2 generates appreciably more vibration than the others. However, because the pump room of Lift 2 was placed on the site slab immediately adjacent to the ram, most of the vibration measured at the ram was actually traceable to the pump rather than to the ram itself. In particular, the large peak at 100 Hz appears to be entirely attributable to the pump.

3.2.3 Noise in pump room

Pump room noise is shown for the three lifts in Fig. 4. Up to 4 kHz the plots are remarkably similar; above this frequency, Lift 1 pump is slightly quieter.

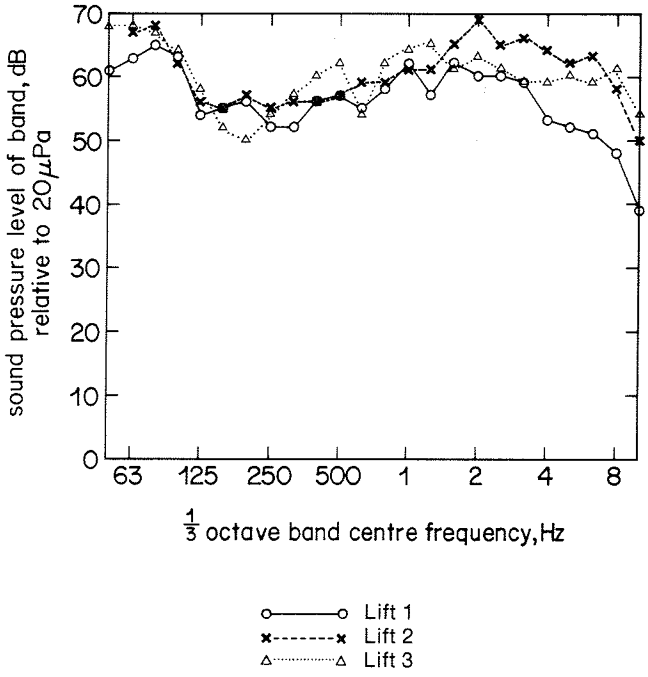

Fig. 4 - Noise in pump room for three lifts: all travelling up, empty.

3.2.4 Noise in lift shaft

Fig. 5 shows the noise measured at the foot of the shaft for the three lifts. Lifts 2 and 3 are very similar; Lift 1 is noisier below 200 Hz and quieter above 1 kHz.

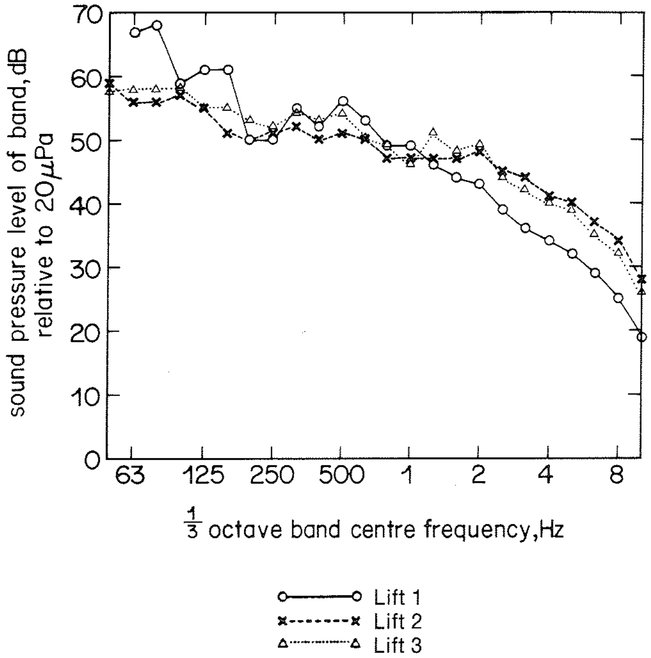

Fig. 5 - Noise at foot of lift shaft for three lifts: all travelling up, empty.

3.3 Implications of results

The most obvious conclusion to be drawn from comparing these three small hydraulic lifts is that in terms of noise nuisance there is little to choose between them. It seems probable that the measured noise and vibration were as dependent on operating environment as on lift type. Three individual installations form far too small a statistical sample for any significant universal conclusions to be drawn, but these results, together with others gathered over a period of time, have not shown any lift manufacturer's products to be either exceptionally quiet or exceptionally noisy.

The lift pumps (and rams) were supported on thin rubber pads; at an estimate, the typical initial thickness was about 10 mm and the static deflection 3 mm. In addition to this, the pump of Lift 1 was placed on a concrete slab, which was in turn supported on 25 mm cork pads of estimated static deflection 1 mm. The mass of the slab was probably of the same order as that of the pump. It is interesting to note that the isolation of the floor from pump vibration does not appear to have been significantly improved by this more elaborate arrangement.

4. MEASUREMENTS ON A HYDRAULIC LIFT MODIFIED BY ITS MANUFACTURER TO REDUCE NOISE

A hydraulic lift installed in a London residential block caused complaints from some occupants, whose bedrooms were close to the pump room; as a result, the manufacturer was asked to recommend and implement some means of noise reduction. The method chosen, was to support the pump on helical steel springs in a steel frame or 'cradle' which was itself supported by rubber pads on the floor of the pump room.

The improvement in isolation achieved by the modification is shown in Fig. 6; the daytime occupational vibration of the building prevented meaningful measurements above about 100 Hz. The structure-borne vibration appears to have been reduced by about 20 dB, at least at low frequencies; certainly, no further complaints were apparently received after the modifications.

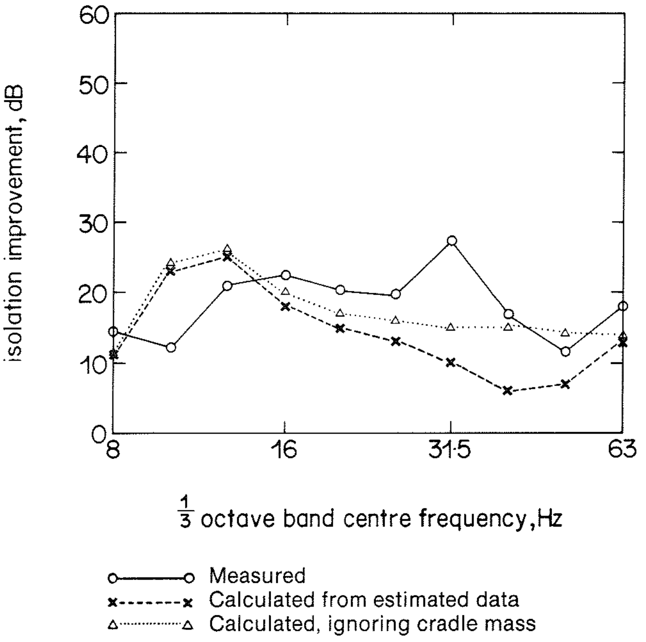

Fig. 6 - Lift with 'cradle' supporting pump: isolation improvement attributable to cradle system.

No detailed technical data were available on the mounting system; the following estimates were therefore made.

Static deflections:	Helical springs	10 mm
	Rubber pads	6 mm
	Original pads	3 mm
Damping factors of mounts		0.1
Mass of cradle relative to pump		0.05

Treating the pump and the pump room floor as pure masses, the pads and springs as pure compliances, and the floor as immovable (simplifications which are valid only at low frequencies) the reduction in the vibrational forces experienced by the floor can be calculated both for the original mounts and for the new system, so that an estimate can be made of the expected improvement in isolation. In Fig. 6, the measured improvement in isolation at low frequencies can be compared with that predicted by the simple model. The most obvious point of disagreement is the peak in the actual isolation at 31.5 Hz, which almost certainly results from a vibrational mode in the cradle.

In fact, the subjective impression obtained on rocking the pump was that the cradle was perceptibly flexible, and that its lowest mode could have been below 31.5 Hz; its behaviour, even at very low frequencies, might therefore be quite complex. If the mass of the cradle is neglected altogether in the model, the calculations yield the third curve shown in Fig. 6, which more closely matches the measured isolation. The use of a steel subframe or cradle may therefore be considered primarily as a method of supporting the pump in a stable manner on helical steel springs. The rubber pads under the cradle probably behave similarly to the rubber 'noise stop pads' traditionally placed directly under helical steel springs, i.e. their effect is very small[1].

5. DESIGN OF A MODIFIED SUSPENSION FOR AN EXISTING LARGE HYDRAULIC LIFT PUMP

In a newly-built regional BBC premises, a large hydraulic (21-passenger) lift had been installed. The car was required to traverse between two floors only, ground and first, and was sited close to an outside wall. On the ground floor, two sets of doors were provided, so that passengers could change floors within the building, and goods could be wheeled into the car from outside. On the first (top) floor, only the inner doors opened. On installation, the pump was sited in a small room between the lift shaft and the outer wall of the building, directly above the short passage on the ground floor by which goods were admitted to the lift car.

Unfortunately, on the first floor, a conference room was sited on one side of the lift shaft, and the office of a senior executive on the other. The door of the pump room (a very poor acoustic barrier) communicated with the conference room, so that conversation there had to cease during use of the lift. The senior executive's office suffered from low-frequency structure-borne noise. In addition, because the lift switchgear was bolted to the lift-shaft side of the office wall, each lift operation generated a quite startling series of impacts.

The locally favoured solution was to move the lift pump into a plant room which was nearer to the centre of the building and separated from the two disturbed areas by a corridor. The only potential problem, was that the thick (450 mm) concrete floor of the plant room (itself quiet in terms of both noise and structural vibration) was also the upper ceiling of the main television studio. While noise disturbance in an office or a conference room is a nuisance, in a broadcasting studio it is, of course, disastrous.

The acoustic noise of the lift pump was measured in its small room and an estimation of the noise that it would generate in the plant room (the projected target area) suggested that airborne noise transmission was unlikely to be a problem. Otherwise, the pump would have had to be enclosed in a lightweight structure or 'blimp' to reduce airborne nuisance. However, the excessive transmission of vibration to the plant room floor would have presented likely problems in the television studio; the means of mounting the pump were therefore considered in detail.

As floor loading was not a problem, it was decided to place the pump on a concrete slab of approximately its own weight, with suitable mountings between pump, slab and floor to ensure optimum isolation. The switchgear was mounted on metal upstands supported on the plant room floor by rubber antivibration mounts; no further problems from this source were either anticipated or encountered.

The antivibration mounts proposed for the pump by the lift manufacturer were of the rubber mat type, of suitably chosen area, and usable if necessary in multiple layers. This approach was encouraged because mounts of this type are less susceptible to modal resonances than, for example, helical steel springs. The configuration adopted is shown diagrammatically in Fig. 7, and has the following properties:

Static deflections:	Mounts under pump	2.8 mm
	Mounts under slab	12.2 mm
	Original pads	2 mm *(estimated)*
Damping factors of mounts		0.1 *(estimated)*
Mass of slab relative to pump		0.8

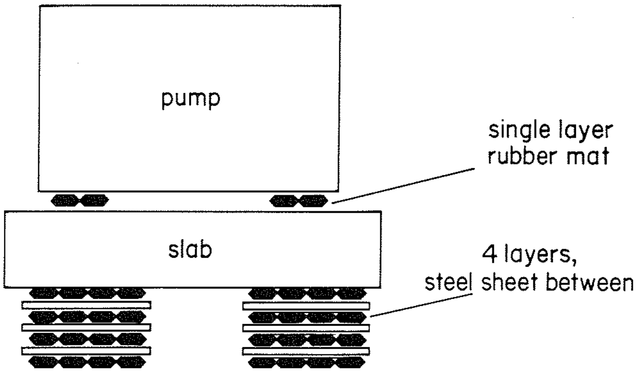

Fig. 7 - Large hydraulic lift: double system of antivibration mounts.

Fig. 8 shows the pump vibration, which is reasonably similar in magnitude and spectrum to that of the smaller pumps previously described; like all the other pumps, it is noisier on ascent than on descent. The airborne noise at 1 m in the new location is shown in Fig. 9; again, it is not dissimilar to that of the other pumps. A noise prediction is also shown, based on the noise in the original pump room with due allowance for the much greater volume of the plant room. At frequencies above about 400 Hz, the pump noise rolls off at about 6 dB per octave compared with the original measurements, and is therefore subjectively very much quieter than predicted. The chief source of high-frequency noise is the turbulent flow of hydraulic fluid in valves and pipes. In the new installation, flexible instead of rigid connections are used between the pump and the hydraulic silencer; it would appear that these rubber hoses, which seem both flexible and lossy, are very effective in damping high-frequency energy in the fluid.

It is interesting to speculate on the improvement in isolation that the new compound system provides over the original single rubber pads. Because the old mounts were never used at the new location, a direct comparison is not possible. However, an estimate may be made, based on two assumptions: first, that the vibration of the pump is independent of the mountings (true at frequencies well above the fundamental resonance, say from 20 Hz upwards); and second, that the vibration of the floor is much less than that of the pump or the concrete plinth (isolations greater than 10 dB lead to errors of 2 dB or less). Given the vibration levels of the pump and of the plinth, and the stiffnesses of the rubber pads, the forces on the floor can be calculated for the old and

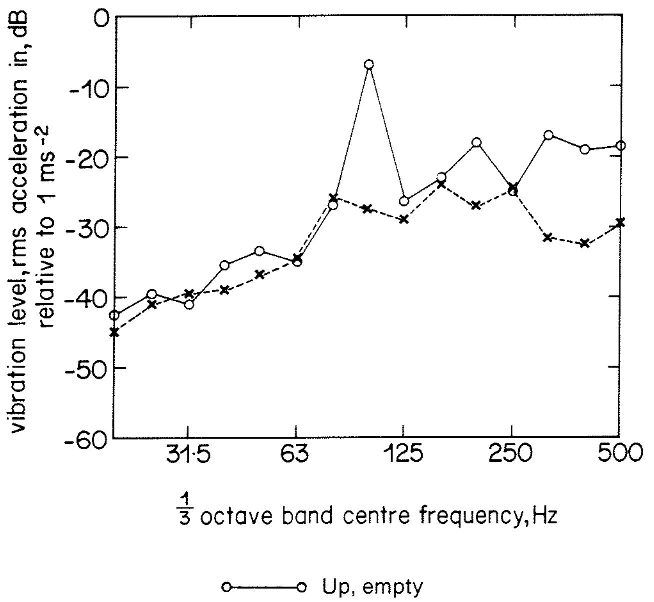

Fig. 8 - Large hydraulic lift: vibration of pump.

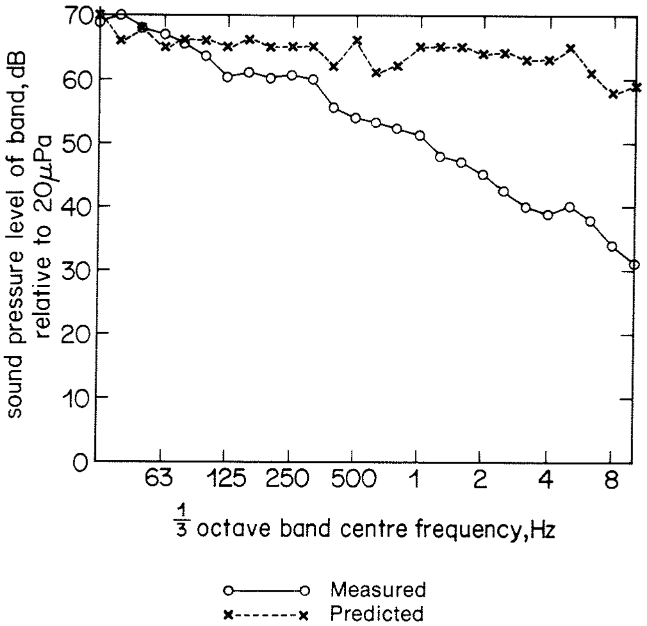

Fig. 9 - Large hydraulic lift, after modifications: airborne noise of pump at 1 m, lift ascending.

new arrangements; the estimated improvement that would have been obtained is shown in Fig. 10. Also plotted is the improvement that would have been predicted by an ideal mass-spring model. Experience in other work has shown that the simple model breaks down above about 100 Hz because of airborne flanking paths; less easily explicable is the disagreement at frequencies below this. The most likely explanation is the presence of vibrational modes in the floor or in the lift pump itself.

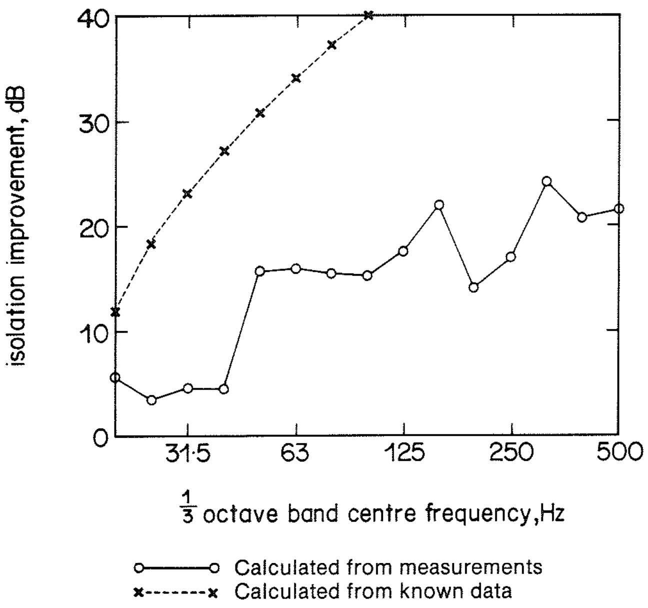

Fig. 10 - Estimated improvement in isolation of large lift pump resulting from intermediate mass and additional mounts.

6. GENERAL RECOMMENDATIONS

The range of lift measurements summarised in the foregoing chapters has been useful in showing both common features and differences between various installations. For the improvement of existing systems or the design of new ones, the following tentative advice is offered.

1. The lift shaft and pump should be sited as far away as possible from sensitive areas. Even in a small building (e.g. local radio centre) a lift shaft placed 3 m away from a studio wall is likely to cause less nuisance than one immediately adjacent.

2. The pump should be sited at the lowest level, preferably on the site slab of the building. The 'softest' antivibration mounts possible should be used (i.e. those with the largest static deflection), consistent with acceptable flexing of the cables and hoses.

3. Where structure-borne vibration generated by the pump presents a potential noise problem, the two-stage system shown in Fig. 7 is worth implementing if funds permit. The concrete slab should have a mass at least comparable to that of the pump. If the compliances of the mounts above and below the concrete slab are different, then the stiffer mounts should be placed between pump and slab to minimise the deflection of the pump on start up.

4. If airborne noise from the pump is a potential problem, the pump room door and its seals should provide adequate acoustic isolation. Where the choice exists, the pump room access should be from a non-critical area.

5. The inner surfaces of the lift shaft should be given a coat of emulsion paint to reduce the generation of dust; this helps to preserve the seals of the hydraulic ram, and to reduce the chances that the ram will become noisy.

6. If structural vibration generated by the ram is a potential nuisance, then the pump should be fitted with a hydraulic 'silencer' or 'muffler'. This reduces fluid pressure fluctuations generated by the pump, and helps to ensure that the ram ascends smoothly.

7. Lift doors generate both airborne and structure-borne noise. Although not usually of a high level, this noise is very characteristic. Careful siting (where the choice exists) and adequate maintenance should minimise problems.

8. For mechanical lifts, the same considerations should be given to the winding-gear as are listed above in 1 - 4 for hydraulic pumps. Lift doors present identical problems, as described in 7 above, whether the hoisting mechanism is mechanical or hydraulic.

7. CONCLUSIONS

A number of passenger lifts, chiefly of the hydraulic type, have been examined, and where possible, noise and vibration measurements have been made. Where modifications to reduce noise have been proposed, and where appropriate, advice has been offered on how this might best be achieved.

As a longer-term result of the work, some general guidelines have been laid down for the improvement of existing installations and the design of new ones.

8. REFERENCE

1. MATHERS, C.D. *and* WALKER, R. 1989. Some properties of antivibration mounts used in building isolation. BBC Research Department Report No. BBC RD 1989/3.